



Designing Stormwater Systems That Last

Performance, resilience, and lessons learned from real-world conditions

COMPANION HANDOUT TO THE APRIL 28, 2026 WEBINAR WITH DR. BILL HUNT, PE

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Throughout the United States, Low Impact Development (LID) practices such as bioretention systems, submerged gravel wetlands, and bioswales are being installed in increasing numbers as communities work to address the stormwater quality and quantity challenges facing their watersheds (Jefferson et al., 2017). However, in the face of rapidly changing hydrologic conditions, many of these practices are no longer able to keep up with the volume of runoff they receive, even when designed, constructed, and maintained in accordance with current standards. As a result, owners are facing higher maintenance costs and more frequent system failures.

This companion piece to the April 28, 2026 Environmental Infrastructure Collaborative webinar of the same name by Dr. Bill Hunt, P.E., highlights lessons learned from decades of implementation and monitoring in North Carolina and applies them to conditions in EPA Region 3. Drawing on that experience, this paper outlines emerging best practices to help stormwater professionals design more resilient, long-lasting LID practices.

Note on Terminology

In EPA Region 3 and related regulatory and design guidance, LID practices are often referred to as green infrastructure or stormwater management practices / best management practices. This document uses Low Impact Development (LID) as the primary term for consistency.

MODELING

The first step in creating a resilient LID is using hydrologic modeling to accurately estimate the amount of runoff that a site will receive. However, changing conditions driven by climate change and urbanization mean that commonly used models are often unable to provide an accurate picture of the storms these systems will experience.

Climate change poses a fundamental challenge to traditional hydrologic modeling. Built on the assumption that rainfall patterns for a given region will remain relatively constant over time, design storms such as the 1% annual chance flood event (100-year storm) are increasingly mismatched with the intensifying rainfall patterns observed in the eastern United States. Current modeling practices rely heavily on the National Oceanic and Atmospheric Administration's (NOAA) Atlas 14, which for most regions, averages rainfall records from the mid-20th century through the early 2000s to estimate the statistical likelihood of storm events (National Oceanic and Atmospheric Administration [NOAA], n.d.). Engineers then size LID practices according to state or local regulatory standards – such as designing to safely manage the 100-year storm.

However, rainfall patterns are shifting (Milly et al., 2008). Across the eastern seaboard, total annual precipitation has increased, and the frequency and intensity of extreme events have risen dramatically (U.S. Global Change Research Program, 2018). As a result, systems designed using historical datasets may not reflect current or future hydrologic conditions.

This challenge is compounded by urbanization, which further increases runoff volumes and peak flow rates. As watersheds develop, impervious surfaces decrease runoff time of concentration and place additional stress on downstream LID practices. Soil disturbance during construction can additionally introduce large sediment loads that can impair performance through premature clogging and otherwise shorten system lifespans.

The result is a growing gap between the stormwater models that regulators currently mandate and observed conditions. As such, many LID practices are now receiving higher flows than anticipated (Lopez-Cantu, 2018), leading to reduced performance and increased maintenance requirements. In some cases, systems may not fully drain between storm events, reducing available storage capacity to provide effective flood control and limiting water quality treatment. Higher peak flows also increase erosion risk and shear stress, raising the risk of damage to berms, slopes, forebays, and outlet structures.

Forthcoming updates such as NOAA Atlas 15 are expected to help close this gap by replacing outdated historical data and statistical methods. These updates incorporate more recent data and forward-looking projects through 2100 to account for climate change (Perica et al., 2025). Until then, practitioners can improve resilience by adjusting design assumptions and applying more conservative modeling approaches.

BEST PRACTICES CHECKLIST

- When possible, use NOAA Atlas 15 or upper-bound (90th percentile) Atlas 14 values when modeling design storms
- Consider applying a 1.2 multiplier to existing design tables to reflect intensifying rainfall
- Consider designing for larger storm events than required (20-yr instead of 10-yr; 500-yr instead of 100-yr)[MKI.1]
- In actively developing watersheds, upsize LID practices to account for increasing impervious land cover and sediment loads from construction

SITING

Selecting the right location is an important early step in designing a successful LID practice. Infiltrative practices such as infiltration basins, permeable pavement, and infiltration swales, perform best in sandy or loamy soils with high permeability and a low Seasonal High Water Table (SHWT). Retentive practices such as constructed wetlands, wet ponds, and bioswales perform best in clay rich soils in high SHWT conditions. Some practices, such as bioretention, function in both infiltration and detention modes and can be applied across a wider range of site conditions. However, it is important to ensure project goals guide practice selection, as these more complex systems are often more expensive than simpler practices while providing similar treatment performance.

TABLE I. LID SITING RECOMMENDATIONS

	Infiltration Practices	Bioretention / Filtration-based Practices (often multi-function)	Retention / Detention Practices
Preferred Soil	Sandy soils with low SHWT	Variable / soil agnostic	Clayey soils with high SHWT
Practice Examples	<ul style="list-style-type: none"> • Infiltration basins • Infiltration swales • Permeable pavement (infiltration-based designs) 	<ul style="list-style-type: none"> • Bioretention cells • Sand filters • Permeable pavement (detention- or filtration-based designs) • Dry detention basins • Underground detention / infiltration systems 	<ul style="list-style-type: none"> • Constructed wetlands • Wet ponds • Wetland swales

Proximity to floodplains is also critical. As flood elevations rise, mapped floodplain boundaries may underrepresent flood risk as compared to observed conditions. As such, LID practices placed near these boundaries are more likely to experience inundation, backflow, and prolonged saturation that can reduce performance and increase maintenance needs.

Anticipated land development should also inform siting decisions. Where upstream construction is expected, designers should assume higher sediment loads and increase pretreatment capacity – especially forebays – to reduce clogging. Systems located downstream of active construction or steep slopes are particularly vulnerable to sediment loading that can shorten system lifespan.



Sediment from upstream construction site entering storm drain inlet.

DESIGN AND CONSTRUCTION

Designers should anticipate common points of failure, particularly where flow is restricted at inlets and outlets. These are especially prone to clogging and can compromise system performance (Beryani et al., 2021). To improve reliability, designers should consider the following:

- Oversizing inlet and outlet structures (grates, curb cuts) to reduce clogging risks
- Armoring inflow points with riprap and directing flow away from forebay berms (Mitchell, 2024)
- Positioning outlets away from unprotected side slopes to reduce erosion risks
- Extending armoring into basin bottoms and to exterior of spillway berms
- Orienting emergency spillways away from buildings and sensitive infrastructure

Resilient design requires planning for maintenance from the outset. Systems that are difficult to access, lack clear maintenance plans, or require the use of hand-tools or other manual equipment for routine tasks are more likely to fall into disrepair. When LID practices are visible, accessible, and integrated into public spaces – with walkways, seating, open sightlines, and educational signage – the public is more likely to value them, and they are more likely to be maintained and monitored over time (Moin et al., 2022).

Poor establishment of vegetation is one of the most common early failure points. When plants do not establish quickly, exposed soils can erode and reduce treatment performance. Designers should provide clear, detailed planting plans that specify species, quantities, and planting zones. Dense planting (approximately 2 feet on center) helps ensure adequate soil coverage and reduce erosion. Establishment periods require frequent watering and care, and summer planting should be avoided where possible to reduce heat stress (Mitchell, 2024).

Forebay berms are particularly vulnerable to erosion and structural failure when fast-flowing water enters the system. Proper flow dispersion and armoring are essential. Inflows should be armored with riprap and directed away from forebay berms to reduce erosive forces. Soil compaction should be specified appropriately (typically 85% for smaller

BEST PRACTICES CHECKLIST

Design

- Match LID practice type to soil conditions and hydrologic function
- Avoid siting near floodplain fringes, where flood elevations may exceed mapped boundaries
- Anticipate common failure points:
- Upsize pretreatment (especially forebays) in urban or developing watersheds
- Oversize inlets/outlets to reduce clogging risk
- Keep outlets away from unarmored berms and side slopes
- Extending armoring into basin bottoms and to exterior of spillway berms
- Direct inflows away from forebay berms
- Direct emergency spillways away from vulnerable infrastructure

Vegetation

- Provide clear planting plans specifying species, quantities, and layouts
- Use dense plantings to reduce erosion
- Avoid summer installation where possible
- Require intensive watering during establishment

Maintenance Access

- Ensure systems are accessible for routine maintenance.
- Integrate LID practices into visible, publicly accessible areas where appropriate

berms and 95% for larger ones) to ensure structural stability (Mitchell, 2024), with a layer of uncompacted topsoil to support vegetation. During construction, erosion control matting and temporary seeding should be used to stabilize exposed soils until root systems establish.

Sediment control during construction is also critical. Without adequate erosion and sediment control measures, large sediment loads can enter newly constructed systems, reducing storage capacity and increasing maintenance needs.

Finally, effective coordination between designers, contractors, inspectors and maintenance staff is essential. Clear communication ensures that systems are built as intended and that maintenance needs are understood before handoff.



Micro-bioretention facility with sparse vegetation due to improper care during establishment

MAINTENANCE

Poor maintenance remains the most common cause of LID system failure (Mitchell, 2024). Even well designed and properly constructed systems will underperform without consistent, routine upkeep.

Many failures occur during project handoff, when critical knowledge about system function and maintenance requirements is lost. Clear, enforceable maintenance agreements, combined with coordinated handoff meetings involving designers, owners, and maintenance personnel, help define responsibilities and reduce reliance on institutional memory or individual staff experience (Mitchell, 2024).

Designers should additionally provide a detailed maintenance plan that outlines routine tasks for hydraulic structures, sediment removal, and vegetation management. These plans should include regular inspection schedules and checklists that address key points of failure, including pump and valve operation, hydraulic structure performance, emergency flood management, and vegetation establishment.

BEST PRACTICES CHECKLIST

- Ensure a clear handoff process so system knowledge is not lost after construction
- Establish enforceable maintenance agreements
- Provide detailed maintenance plans covering hydraulic structures, sediment removal, and vegetation establishment and long-term care:
 - Include inspection schedules with checklists of common issues
 - Include establishment-phase and long-term vegetation maintenance guidance
 - Include visual references of installed plant species
- Conduct post storm inspections to identify damage early and maintain performance
- Where feasible, consider Continuous Monitoring & Adaptive Control (CMAC) systems

Where feasible, systems should be inspected after major storm events, and storage facilities should be drained in advance of forecasted large storms to improve performance and catch any damage early (Mitchell, 2024).

Vegetation maintenance requires particular attention. Maintenance plans should include recommendations for both plant establishment and long term care. Establishment guidance should include watering frequency, plant replacement criteria, and erosion control measures during early growth. Long term maintenance should identify no mow zones, outline invasive species management, and include visual references of installed plant species to help maintenance crews distinguish intended vegetation from weeds. Clear visual documentation reduces the risk of accidental damage to plantings (Mitchell, 2024).

Where feasible, real-time or Continuous Monitoring and Adaptive Control (CMAC) systems can further improve maintenance reliability. These systems allow operators to track water levels in real time, receive alerts when conditions fall outside design thresholds, and actively manage storage by drawing down systems ahead of storm events. This reduces the likelihood of overtopping, improves treatment performance, and provides a more accurate understanding of system behavior than periodic inspections alone (Bartos, Wong, & Kerkez, 2018).

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IMAGE CREDIT

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